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ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Simulated Sonic Boom as an Avalanche Trigger

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A linear array of detonating cord was used to simulate a sonic boom. The boom from such charges was directed toward the fracture zone of a small avalanche path where the snow was unstable, as indicated by natural avalanches in the area. On three of four tests, avalanches were released by a boom of 12 pounds per square foot (60 kg f/m<sup>2</sup>) overpressure after withstanding lesser booms. One of the avalanches had a fracture face 8 feet 11 inches (272 cm) deep.

Keywords: Avalanche, sonic boom.

It appears obvious that snow can become unstable enough to be released by a sonic boom, since natural avalanches often occur with no obvious trigger. What is not known is the degree of instability at which sonic booms become important avalanche triggers. The consequences of widespread avalanche activity from frequent supersonic flights could be serious in areas of concentrated winter sports activity, at mining or hydroelectric sites, or along major mountain highways. As logical as the above arguments may be, there are still few well-documented cases of avalanches released by sonic booms (Vivona 1970).

Several attempts have been made in the western United States to release avalanches by supersonic overflights of military aircraft. So far, the results have been inconclusive. In one case,<sup>2</sup> fighter planes were maneuvered to concentrate and direct the boom at specific targets. Although a few avalanches were released, no data were taken on the overpressures, estimated at 3 to 4 pounds per square foot (p.s.f.), or the

snow conditions. In another case (Lillard et al. 1965), logistics and communication problems delayed the tests so long the snow could not be released by the booms nor by artillery fire.

In this study, conventional explosives were used to simulate the shape, duration, and magnitude of the pressure-time trace of a sonic boom. Following the techniques of Hawkins and Hicks (1966), several strands of 50-grain detonating cord (fig. 1) were arranged to give a 100-millisecond N-wave. The magnitude of the overpressure was measured as a function of the distance from the end of the charge, and a calibration curve was prepared (fig. 2) (Mellor and Smith 1967).

Booms were simulated on two small avalanche paths near Berthoud Pass, Colorado. Although these paths occasionally avalanche naturally, and have been released numerous times in the past years by explosives tossed on the snow, they are considered two or three times more stable than several others in the vicinity.

During a test run, the 80-foot (24.4-m) long charge was suspended beneath a cable rigged above the long axis of the slide path. A system of pulleys allowed the end of the charge to be pointed toward the target area, and to be positioned properly for the desired overpressure (fig. 3). The charge was detonated by an ignition cap.

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<sup>2</sup>Oral communication with Max E. Edgar, U.S. National Park Service, during Interagency Avalanche Conf., Santa Fe, N. Mex., April 1960.

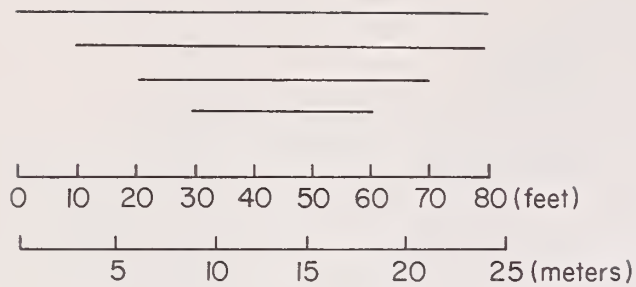


Figure 1.—Array of four strands of 50-grain primacord as used to simulate 100-millisecond N-wave in this study (1 foot = 0.305 meter).

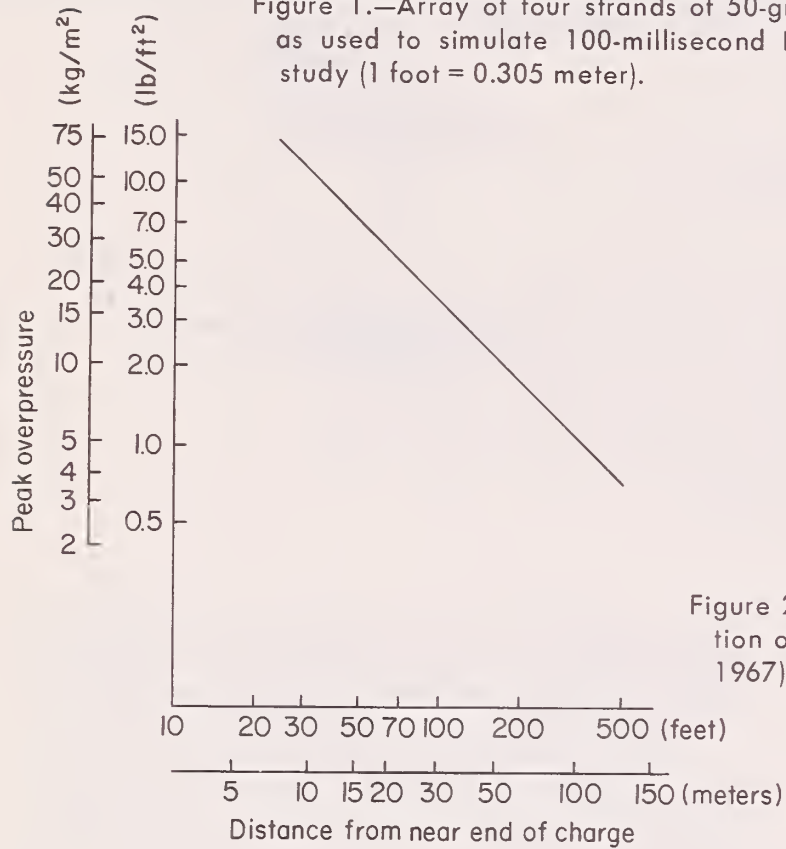


Figure 2.—Distance-overpressure calibration for simulation of 100-millisecond sonic boom (Mellor and Smith 1967). (1 lb/ft<sup>2</sup> = 4.88 kg/m<sup>2</sup> or 0.488 g/cm<sup>2</sup>)

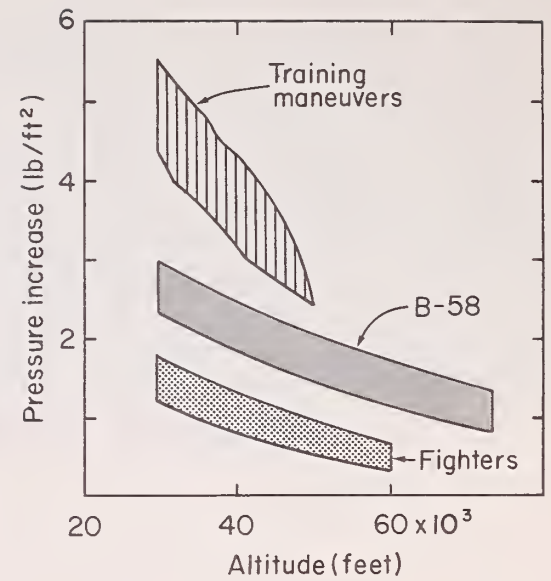


Figure 4.—Sonic boom exposure levels for routine military flight operations (after Crow 1966).

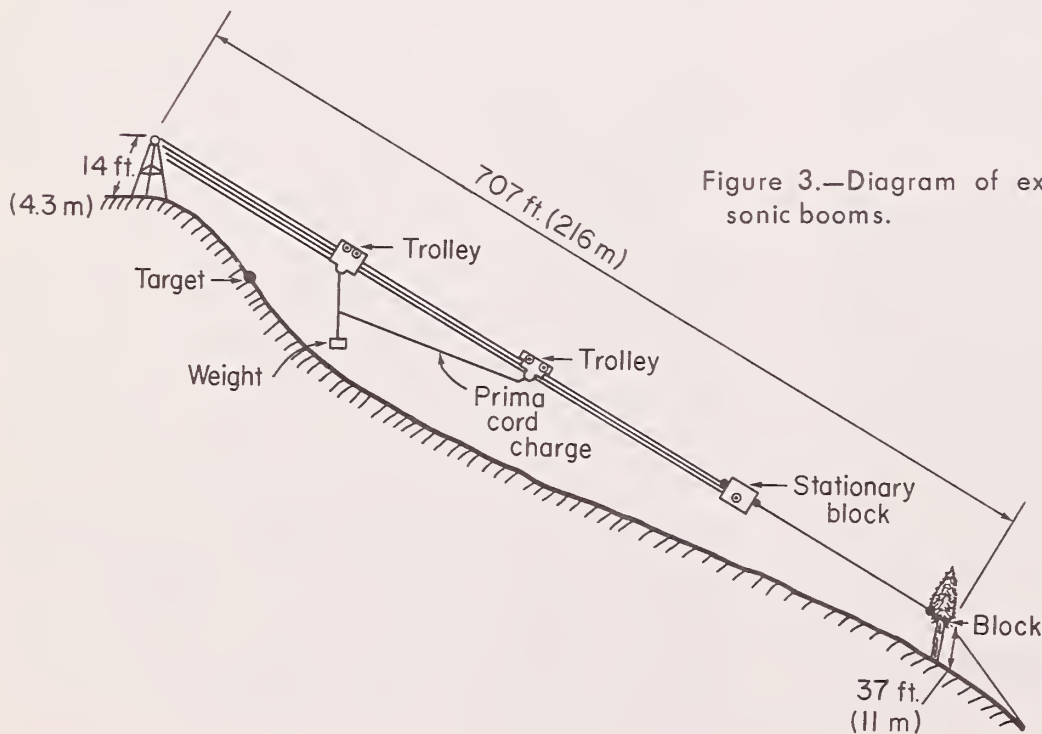


Figure 3.—Diagram of experimental setup to simulate sonic booms.

When avalanche hazard was considered high, the more unstable of the two slopes was subjected to sonic booms of 3, 6, and 12 p.s.f. (15, 30, and 60 kgf/m<sup>2</sup>) overpressure. These correspond roughly to normal, twice normal, and four times normal for level supersonic flight (fig. 4) (Carlson and McLean 1966). If no avalanche occurred, a 6- to 9-pound charge of HDP-1<sup>3</sup> was tossed into the target area to test snow stability in the same manner used in previous years when the area was used for skiing. At the end of each test, snow density, ram

hardness, and snow crystal type were determined.

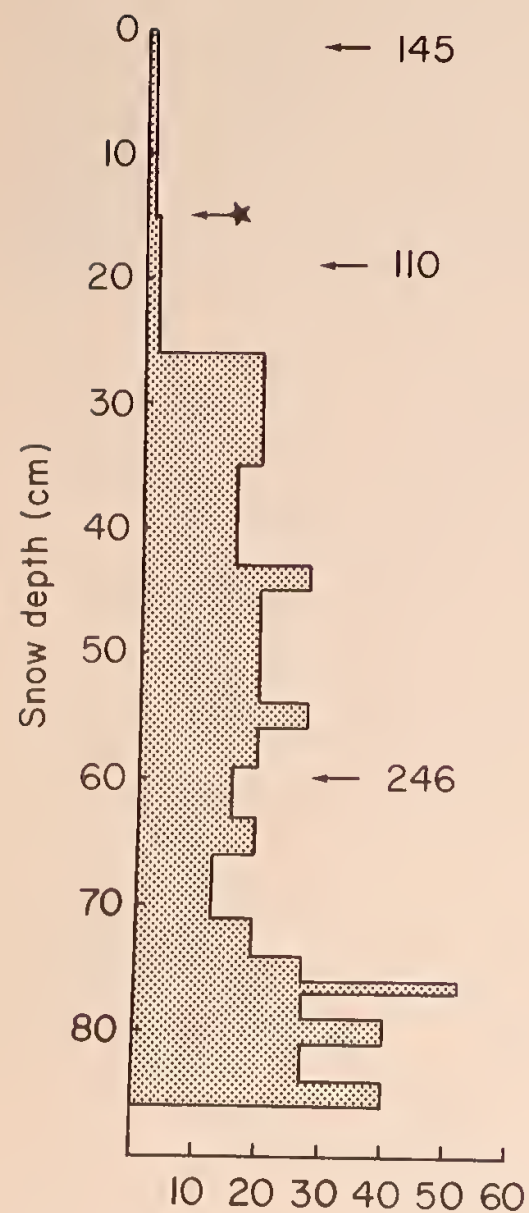
Three tests were run during the winter of 1969-70 and one the following winter. The simulated booms on February 5, 1970 produced a few cracks in the snow, but no avalanches. A 3-pound (1.36 kg) charge of HDP detonated in the target area, however, did release a 5-inch (13-cm) soft slab over about 20 percent of the area. This test was run early in a storm period that produced both hard and soft slab avalanches, most of which were small in size and the result of explosive control action (table 1). The 9 inches (23 cm) of fresh snow reported for February 4 contained 0.6 inch (15 mm) of water and fell with moderate winds and temperatures that had warmed 8° to 9° F. from the previous 2 days (table 2). From the snow profiles (fig. 5A), it appears that there were about 10 inches (25 cm) of new snow on top of a tough layer that was probably the prestorm surface layer.

<sup>3</sup>Dupont HDP-1 has a detonation rate of 24,000 feet per second, compared to 60 percent gelatin which has a rate of 16,000 feet per second. The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

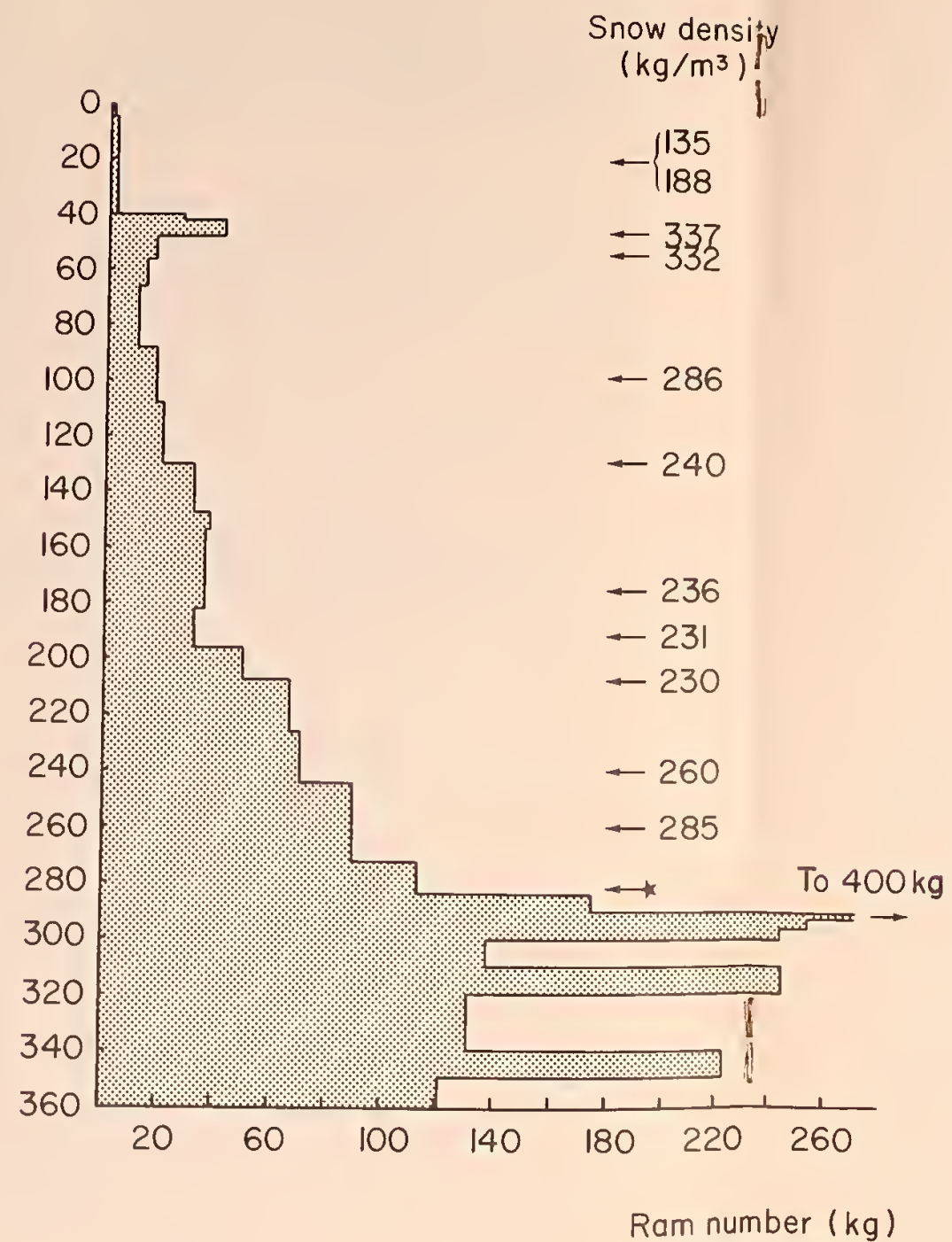
Table 1.--Summary of avalanches within 12-mile (20 km) radius of the test site (test day is underlined; avalanches released by the booms are not listed)

Date	Type of avalanche			Trigger		Rating system for size					Total avalanches
	Hard slab	Soft slab	Loose	Natural	Explo- sive	Sluffs	Small	Medium	Large	Major	
						(1)	(2)	(3)	(4)	(5)	
						Number					
February 1970											
2,3											0
4		1			1	1					1
5	1	4		2	3	1	1	2	1		5
6	2				2		1	1			2
7	2				2	1	1				2
Total	5	5	0	2	8	3	3	3	1		10
March 1970											
23		1		1			1				1
24	1	1			2			1	1		2
25	4	1		3	2		3		2		5
26	2				2		1	1			2
27	1				1		1				1
Total	8	3	0	4	7	0	6	2	3		11
April 1970											
18		5		3	2	1	3	1			5
19		2			2	1	1				2
20		3	1	2	2		1	2	1		4
21		1		1				1			1
22											0
Total	0	11	1	6	6	2	5	4	1		12
February 1971											
6	4				4		3	1			4
7											0
8	4			4			2	2			4
9											0
10											0
Total	8	0	0	4	4	0	5	3	0		8

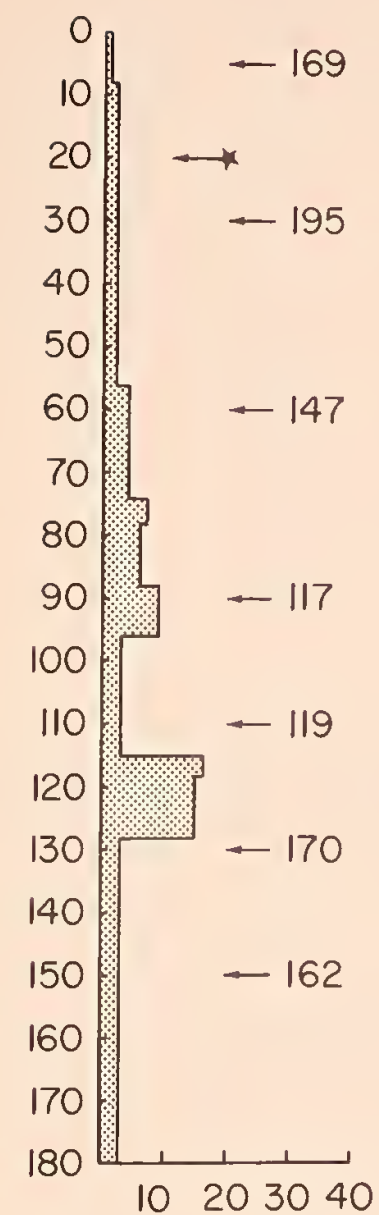
A. FEBRUARY 5, 1970



B. MARCH 26, 1970



C. APRIL 21, 1970



D. FEBRUARY 9, 1971

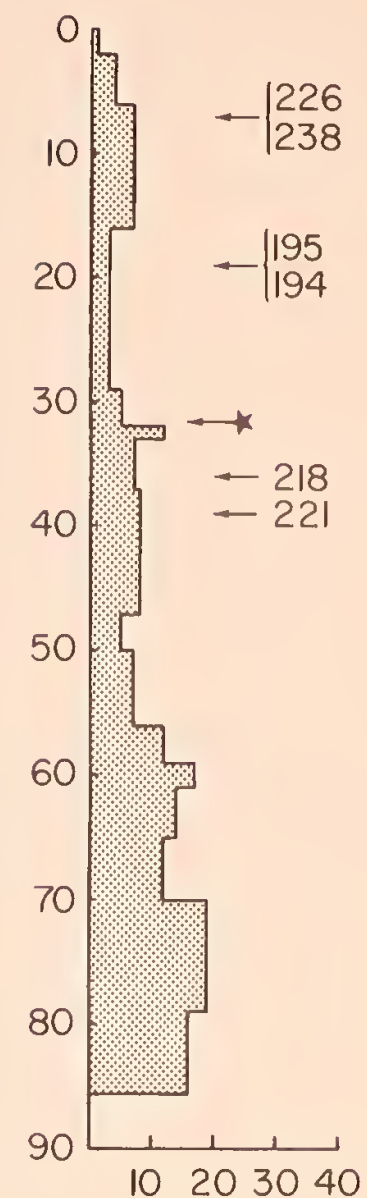


Figure 5.—Rommsonde profiles of the snow cover on test days. Notice the change in scale for port B.

C. APRIL 21, 1970

D. FEBRUARY 9, 1971

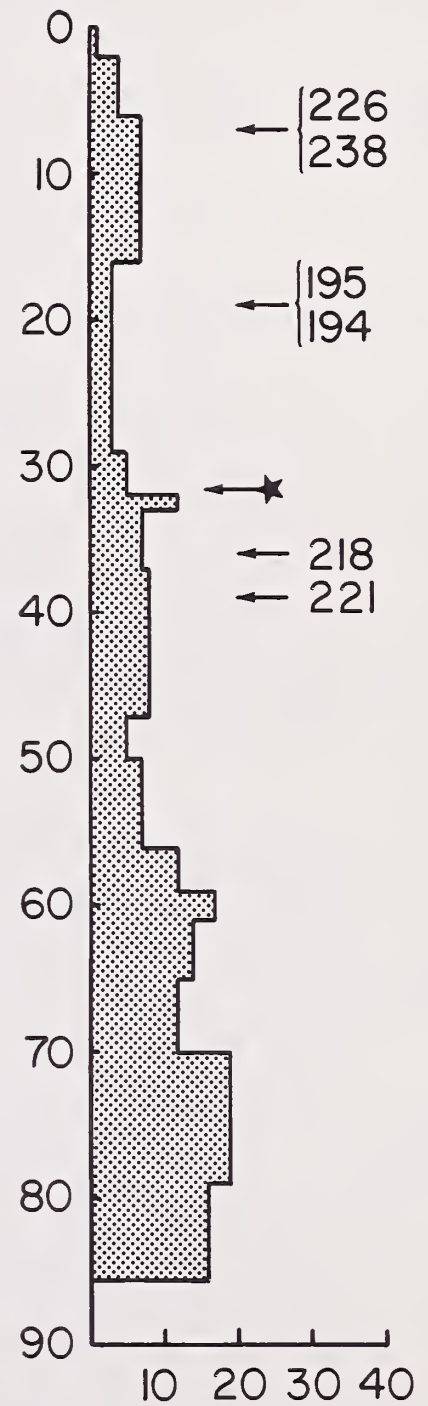
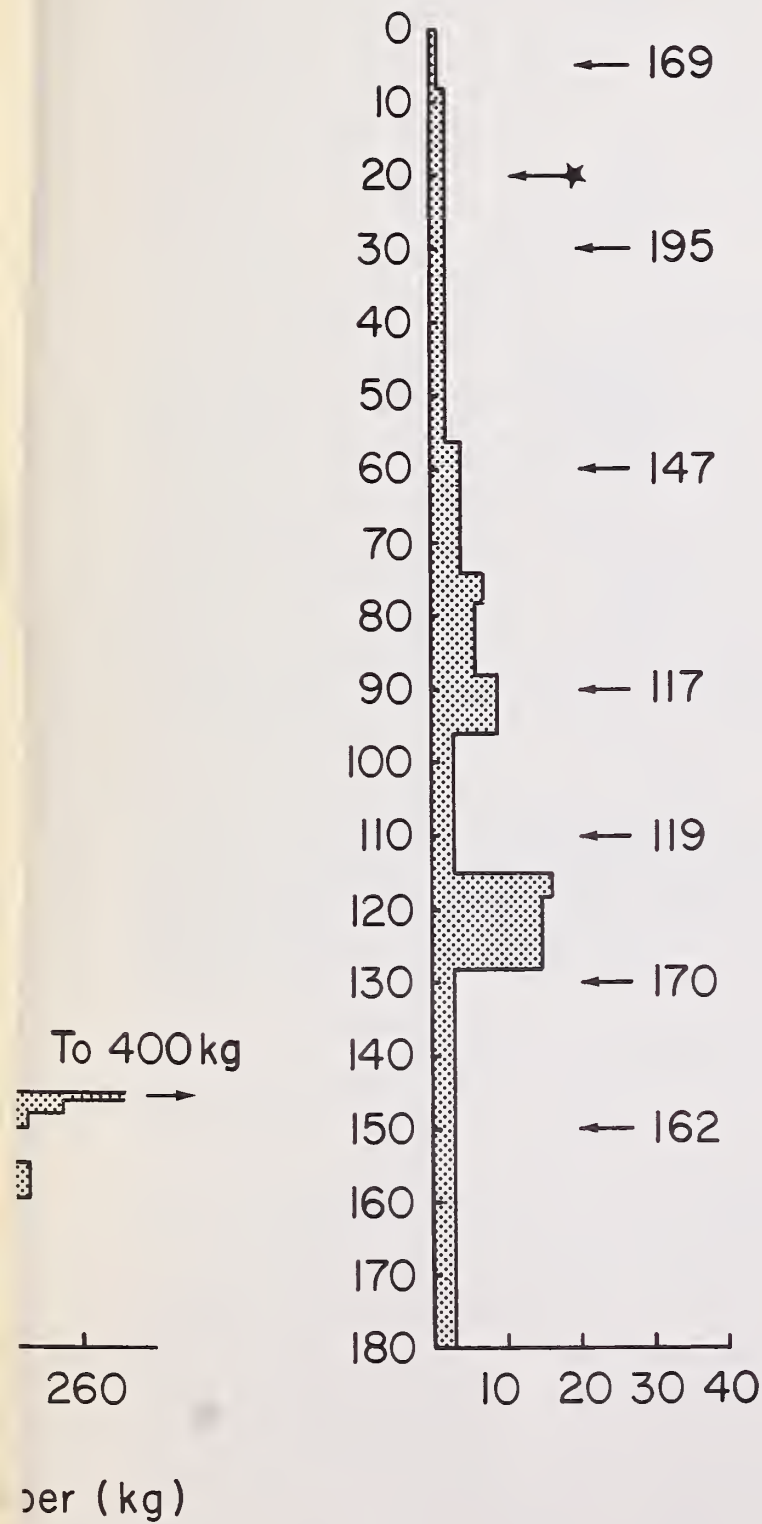


Figure 5.—Rammsonde profiles of the snow cover on test days. Notice the change in scale for part B.

Table 2.--Weather 3 days prior to each sonic boom test (date of the test is underlined)

Date	Precipitation		Temperature		Wind		
	New snow	Water equivalent	Maximum	Minimum	Direction	24-hour average	Gust
	- - Inches - -		- - °F - -			m.p.h.	
February 1970							
2	2.0	0.17	10	-1	NW	21	54
3	1.5	.09	7	-1	NW-WNW	22	52
4	9.0	.60	19	6	WSW-SW	17	58
<u>5</u>	4.0	.22	19	4	WSW-W	15	46
March 1970							
22	4.0	.28					
23	.5	.04	23	2	WNW	20	55
24	--	--	31	12	WNW	19	80
25	11.5	.89	34	1	VAR-NW	21	50
<u>26</u>	( <sup>1</sup> )	( <sup>1</sup> )	11	-6	NW-VAR-NW	12	34
April 1970							
18	6.0	.45	35	15	SW-NW	16	40
19	2.5	.14	22	9	NW-WSW-NW	12	35
20	9.5	.79	22	3	NNW-SW	18	45
<u>21</u>	1.0	.06	18	4	SW-VAR	16	41
February 1971							
6	3.5	.27	2	-9	WNW	17	52
7	1.0	.07	2	-18	NW	22	50
8	2.0	.19	5	-16	NW	23	42
<u>9</u>	1.0	.07	11	-3	NW	16	40

<sup>1</sup>Trace.

The hand-placed explosive charge released just the fresh snow with a density of  $145 \text{ kg m}^{-3}$  and a ram hardness of 1 kg or less. This snow slid on older snow that was a little tougher (ram no. 2 kg) than the new snow, in spite of its slightly lower density ( $110 \text{ kg m}^{-3}$ ).

On March 26, 1970, a major hard-slab avalanche was released by a 12-p.s.f. boom after the snow had withstood a 6-p.s.f. boom. This avalanche covered the entire test area (250 by 350 feet, or 75 by 110 m), had a fracture face 8 feet 11 inches (272 cm) deep, and a few debris blocks that measured 10 by 8 by 6 feet (3 by 2.5 by 2 m). The test was run toward the end of a period of predominantly hard slab activity (table 1). On March 25, 11.5 inches (29 cm) of new snow with 0.89 inch (23 mm) of water fell on the test site, accompanied by high temperatures and winds that gusted to 50 m.p.h. (22 m/sec). On the test day, precipitation dropped to a trace, winds slackened but continued to gust to 34 m.p.h. (15 m/sec), and temperature dropped sharply (table 2). The snow profile at the test site (fig. 5B) showed 16 inches (40 cm) of new,

soft snow on top of about 20 inches (50 cm) of tougher snow. The high density of this young snow 40 to 50 cm below the surface is a good indication it was initial hard slab (Martinelli 1971), most likely deposited by the high wind of March 24 and 25. The fracture produced by the boom penetrated the new snow and well into the older snow before encountering a very tough layer. The avalanche ran on this hard, tough layer.

On April 21, the 12-p.s.f. boom released an 8-inch (20-cm) soft slab avalanche that ran about 100 feet (30 m) after 3- and 6-p.s.f. booms produced nothing but small surface cracks. Nine- and six-pound (4.1- and 2.7-kg) charges of HDP, detonated in the area for safety's sake, gave no additional fractures or avalanches. This test was made at the end of a moderate cycle of soft slab avalanche activity (table 1). The release was in fresh snow probably deposited the day before the test, when 9.5 inches (24 cm) of new snow with a water equivalent of 0.8 inch (20 mm) fell with moderate winds and warm temperatures (table 2).

The test on February 9, 1971 gave a small slab avalanche (130 ft wide by 150 ft long by 1 ft deep) and some surface cracks in response to a 12-p.s.f. boom. The 3- and 6-p.s.f. booms were not made because of mechanical problems caused by gusty winds. For the 3 days prior to the test, temperatures were low ( $\leq 5^{\circ}\text{F.}$ ), precipitation less than 0.27 inch (7 mm) of water/day, and winds averaged 16 to 22 m.p.h. (7 to 10 m/sec) with gusts to 52 m.p.h. (23 m/sec). Four hard slab avalanches were released by explosives on February 6, and four more ran naturally during the night of February 8 on avalanche paths near the test site. Snow released by the boom was mostly wind deposited, with densities between 195 and 240 kg m<sup>-3</sup> and ram hardness of 3 to 6 kg. This rather tough soft slab ran on a layer that was only slightly harder than the avalanching snow.

All avalanches released by simulated sonic booms required a threefold to fourfold amplification of the overpressure expected from normal supersonic flights. How often and under what circumstances terrain and atmospheric conditions in the mountains would give this amplification is not known (Roberts et al. 1967, Cook and Goforth 1967). Modeling experiments have shown, however, that certain terrain features can be expected to amplify peak overpressure 2 to 4 times, and that amplifications of 8 to 12 times normal are possible (Bauer and Bagley 1970). The simulated booms released avalanches only during periods when one-third or more of the avalanche activity in the local area was the result of natural releases.

In summary, this study suggests that, during periods of frequent natural avalanches, threefold to fourfold amplification of a normal sonic boom can be expected to release additional avalanches, some of which could be quite large.

#### Literature Cited

Bauer, A. B., and C. J. Bagley.

1970. Sonic boom modeling investigation of topographical and atmospheric effects. Rep. No. FAA-NO-70-10, July 1970, 212 p. (AD 711124). Prepared for Dep. Trans., Off. of Noise Abatement.

Carlson, H. W., and F. E. McLean.

1966. The sonic boom. *Int. Sci. and Tech.* 55 (July 1966).

Cook, J. C., and T. Goforth.

1967. Seismic effects of sonic booms. p. E1-E17. **In** *Sonic Boom Experiments at Edwards Air Force Base. Interim Rep., Nat. Sonic Boom Eval. Office, 1400 Wilson Blvd., Arlington, Va. (AD 655310).*

Crow, L. W.

1966. Sonic boom. U. S. Air Force 7th Weather Wing Pam. 6, WWP 105-1-1, 43 p.

Hawkins, S. J., and J. A. Hicks.

1966. Sonic bang simulation by a new explosive technique. *Nature* 211(5055): 1244-1245.

Lillard, David C., Tony L. Parrott, and Dale G. Gallagher.

1965. Effects of sonic booms of varying overpressures on snow avalanches. *Fed. Aviat. Agency Rep. SST 65-9*, 10 p.

Martinelli, M., Jr.

1971. Physical properties of alpine snow as related to weather and avalanche conditions. *USDA Forest Serv. Res. Pap. RM-64*, 35 p., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Mellor, Malcolm, and North Smith.

1967. Simulation of sonic booms by linear explosive charges. *U.S. Army Materiel Command, Cold Regions Res. and Eng. Lab. Tech. Note*, March 1967, 15 p. Hanover, N.H.

Roberts, C., W. Johnson, G. Herbert, and W. A. Hass.

1967. Meteorological investigation. p. D1-D11. **In** *Sonic Boom Experiments at Edwards Air Force Base. Interim Rep., Nat. Sonic Boom Eval. Office, 1400 Wilson Blvd., Arlington, Va. (AD-655310).*

Vivona, F. M.

1970. Considerazioni Preliminari uno Studio Sistemático del Fenomeno delle Valanghe (Preliminary considerations for a systematic study of avalanche phenomena). *Italy. Istituto di Fisica dell'Atmosfera, Rome. CENFAM Papers IFA CP No. 218*, 13 p. (MGA 22.11-442).

